Field Test Program to Develop Comprehensive Design, Operating and Cost Data for Mercury Control Systems on Non-Scrubbed Coal-Fired Boilers

Quarterly Technical Report
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Principal Authors
Richard Schlager
ADA Environmental Solutions, LLC
8100 SouthPark Way, B-2
Littleton, Colorado 80120

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DISCLAIMER

ABSTRACT

With the Nation's coal-burning utilities facing the possibility of tighter controls on mercury pollutants, the U.S. Department of Energy is funding projects that could offer power plant operators better ways to reduce these emissions at much lower costs.

Mercury is known to have toxic effects on the nervous system of humans and wildlife. Although it exists only in trace amounts in coal, mercury is released when coal burns and can accumulate on land and in water. In water, bacteria transform the metal into methylmercury, the most hazardous form of the metal. Methylmercury can collect in fish and marine mammals in concentrations hundreds of thousands times higher than the levels in surrounding waters.

One of the goals of DOE is to develop technologies by 2005 that will be capable of cutting mercury emissions 50 to 70 percent at well under one-half of today's costs. ADA Environmental Solutions (ADA-ES) is managing a project to test mercury control technologies at full scale at four different power plants from 2000 – 2003. The ADA-ES project is focused on those power plants that are not equipped with wet flue gas desulfurization systems.

ADA-ES will develop a portable system that will be moved to four different utility power plants for field testing. Each of the plants is equipped with either electrostatic precipitators or fabric filters to remove solid particles from the plant's flue gas.

ADA-ES's technology will inject a dry sorbent, such as fly ash or activated carbon, that removes the mercury and makes it more susceptible to capture by the particulate control devices. A fine water mist may be sprayed into the flue gas to cool its temperature to the range where the dry sorbent is most effective.

PG&E National Energy Group is providing two test sites that fire bituminous coals and both are equipped with electrostatic precipitators and carbon/ash separation systems. Wisconsin Electric Power Company is providing a third test site that burns Powder River Basin (PRB) coal and has an electrostatic precipitator for particulate control. Alabama Power Company will host a fourth test at its Plant Gaston, which is equipped with a hot-side electrostatic precipitator and a downstream fabric filter.

During the seventh reporting quarter, progress was made on the project in the following areas:

<u>PG&E NEG Brayton Point Station</u>

- Sorbent injection equipment was installed at the site during the quarter.
- Test plans were prepared for the field testing phase of the project.
- Baseline testing was completed during the quarter and parametric testing was begun.

- A paper summarizing the full-scale tests was written and submitted to A&WMA for presentation at the annual meeting in June 2002.

Technology Transfer

- A number of technical presentations and briefings were made during the quarter. Notable among them are papers published in the A&WMA EM journal and Pollution Engineering. Also, information was provided to the EPA MACT Working Group and a paper was presented at the annual A&WMA meeting.

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LIST OF GRAPHICAL MATERIALS

There are no graphical materials included in this report.

EXECUTIVE SUMMARY

ADA-ES began work on a Cooperative Agreement with the Department of Energy in October, 2000 to demonstrate full-scale mercury control systems at coal-fired power plants. The project is the next step in the process of obtaining performance and cost data on full-scale utility plants for mercury control systems. Power generating companies that have entered into contracts with ADA-ES are PG&E National Energy Group, Wisconsin Electric Power Company and Alabama Power Company. During the three-year, $6.8 million project, integrated control systems will be installed and tested at four power plants. ADA-ES is responsible for managing the project including engineering, testing, economic analysis, and information dissemination functions.

As of the seventh reporting quarter, progress on the project has been made in the following areas:

- Alabama Power Company Plant Gaston – field testing has been completed.
- Wisconsin Electric Pleasant Prairie Power Plant – field testing has been completed.
- PG&E NEG Brayton Point Station – baseline testing was completed and testing was begun on the parametric test series.

Several technical papers were presented on the project during the seventh reporting quarter at the annual A&WMA meeting and to several architect and engineering firms that are interested in including mercury control systems into the emissions control projects that they are currently specifying.

INTRODUCTION

Cooperative Agreement No. DE-FC26-00NT41005 was awarded to ADA-ES to demonstrate mercury control technologies on non-scrubbed coal-fired boilers. Under the contract, ADA-ES is working in partnership with PG&E National Energy Group, Wisconsin Electric Power Company, Alabama Power, and EPRI to design and engineer systems to maximize effectiveness and minimize costs to curtail mercury emissions from power plant flue gases. Reports estimate that mercury control could cost the industry from $2 to $5 billion per year. Much of these costs will be associated with power plants that do not have wet scrubbers as part of their air pollution control configurations. The four plants that are being evaluated during the program are typical of this type of application which is found at 75% of the nearly 1100 units that would be impacted by new regulations.

Detailed topical reports will be prepared for each site that is tested under the program. Quarterly reports will be used to provide project overviews and technology transfer information.

EXPERIMENTAL

Field work was conducted on the project during the seventh reporting quarter at PG&E's Brayton Point Station in the form of baseline testing and beginning the parametric test series. Detailed results of the testing at each power plant will be provided in separate topical reports.

Technology Transfer

Technology transfer activities continued during the seventh reporting quarter of the project. Reference citations of the formal presentations are provided below:

Krause, K. (2002). "Mercury Control, Sensible solutions that balance environmental risk and energy impacts," A&WMA *EM Journal*, pp. 22-28, April.

Bustard, C.J. (2002). "Full-Scale Test of Mercury Control on Coal Fired Boilers," presented at the Western Coal Council Seminar on Burning PRB Coal, Louisville, KY, April 9.

Monroe, L. and R. Miller (2002). "Mercury and Utility Multi-pollutant Control," *Pollution Engineering*, pp. 42-43, April.

Durham, M.D. (2002). "Control of Mercury Emissions by Injecting Powdered Activated Carbon (PAC)," presentation to the Utility MACT Working Group, U.S. Environmental Protection Agency, Research Triangle Park, NC, May 13.

Starns, T., C.J. Bustard, M.D. Durham, C. Lindsey, C. Martin, R. Schlager, B. Donnelly, S. Sjostrom, P. Harrington, S. Haythornthwaite, R. Johnson, E. Morris, R. Chang and S. Renninger (2002). "Full-Scale Test of Mercury Control with Sorbent Injection and an ESP at Wisconsin Electric's Pleasant Prairie Power Plant," to be presented at the 95th A&WMA Annual Meeting, Session AE-1, Baltimore, MD, June 23-27.

Bustard, C.J., M. Durham, C. Lindsey, T. Starns, K. Baldrey, C. Martin, R. Schlager, S. Sjostrom, R. Slye, S. Renninger, L. Monroe, R. Miller and R. Chang (2002). "Full-Scale Evaluation of Mercury Control with Sorbent Injection and COHPAC at Alabama Power E.C. Gaston," special edition *JAWMA*, June.

Durham, M.D. and C.M. Martin (2002). "ADA-ES/DOE Mercury Control Program," presentation to Sargent & Lundy, Chicago, IL, May 31.

Durham, M.D. and C.M. Martin (2002). "ADA-ES/DOE Mercury Control Program," presentation to Washington Group, Englewood, CO, May 29.

Websites Containing ADA-ES Presentations to Regulatory Agencies

Two regulatory agencies have placed information about the project onto their websites. References for these sites are:

Wisconsin DNR website:
http://www.dnr.state.wi.us/org/aw/air/reg/mercury/rule.htm

EPA Electric Utility section 112 Rule Making website:
http://www.epa.gov/ttn/atw/combust/utiltox/utoxpg.html

RESULTS AND DISCUSSION

The major efforts during the seventh reporting quarter focused on completing baseline testing at Brayton Point, and initiating the parametric test series. Detailed results of the testing at each power plant will be provided in separate topical reports.

CONCLUSION

Work began on Cooperative Agreement No. DE-FC26-00NT41005 in October 2000. Initial activities include holding a project kickoff meeting, securing the fourth test site (Alabama Power Company Plant Gaston), and performing various planning and administrative functions. Field testing began during the second reporting period at Plant Gaston, and test planning for the remaining sites began. Test work was completed at the Gaston site during the third reporting period. Site preparations were completed and field testing began at Wisconsin Electric during the fourth reporting period and all site work was completed during the fifth reporting quarter. Sorbent screening activities were completed at Brayton Point during the sixth reporting quarter. Baseline testing was initiated at Brayton point in the seventh quarter and parametric testing began.

REFERENCES

None this reporting period.

LIST OF ACRONYMS AND ABBREVIATIONS

A&WMA	Air & Waste Management Association
DOE	Department of Energy

ATTACHMENT A

Accomplishments and Status Assessment
April 1, 2002 – June 30, 2002

- **General**
  The project is progressing on schedule without any major deviations from plan.

- **Alabama Power Company's Plant Gaston**
  This facility was the first to be tested in the program. Prebaseline testing was completed in February, 2001 and the parametric test series was performed in March, 2001. The long-term test series was completed during April, 2001. The test facility was decommissioned during May. Economic analysis and topical report were started in June and are continuing. Ontario Hydro test results have been completed.

- **WEPCO Pleasant Prairie Power Plant**
  Sorbent screening testing was completed at Pleasant Prairie in June, 2001. Equipment installations were completed in August, 2001. WEPCO hosted a public site tour of the mercury control system at the end of August as part of the A&WMA Specialty Conference on Mercury Emissions. Equipment check-out was completed in September and Baseline and Parametric testing began during September 2001. Long-term testing was completed in November, and the mercury control equipment was removed during December and moved to PG&E NEG Brayton Point.

- **PG&E NEG Brayton Point Station**
  Prebaseline testing was performed at Brayton Point during June 2001. Mercury emissions measurements were made at the station during the summer of 2001 as required by the state of Massachusetts. The site was visited in July 2001 to evaluate the ductwork, port locations, equipment locations and platform needs. Some site preparation work was done during September 2001. The mercury control equipment was received by the station in December 2001. Sorbent screening testing was performed at the site in February 2002, baseline testing was completed in June 2002 and parametric testing was begun during June 2002.

- **PG&E NEG Salem Harbor Station**
  Prebaseline measurements were made at Salem Harbor during February 2001. Mercury emissions measurements were made at the station during July 2001 as required by the state of Massachusetts. Additional prebaseline testing, parametric and long-term testing of Salem Harbor is scheduled for Fall, 2002. Ash samples are being analyzed by Microbeam Technologies and results are being evaluated.

- **Technology Transfer**
  A number of technology transfer activities have taken place since the project began in October 2000. More activities are planned for future conferences, symposia and technical publications. Presentations were made during the quarter at a Western Coal Council seminar, at the annual A&WMA meeting, at the EPA Utility MACT Working Group and to two architect/engineering firms. Papers about the project were prepared for Pollution Engineering, the A&WMA EM journal

ATTACHMENT B

Technical Papers, Press Releases and Other Published Information

Pollution Engineering
Helping You Engineer A Better Environment

CASEBOOK

Mercury and Utility Multi-pollutant Control

Pollution Engineering, April 2002

By **Larry Monroe, PhD** and **Richard Miller**

Southern Company is one of the largest producers of electricity in the U.S. It is the parent firm of Alabama Power, Georgia Power, Mississippi Power, Gulf Power, Savannah Electric, Southern Nuclear, and Southern Company Generation and Energy Marketing. The company has a long-standing commitment to seek ways to produce more environmentally efficient energy. Since 1990, Southern has invested more than $500 million in environmental controls and more than $360 million in environmental research and development.

There are important benefits to a combination of technologies in multi-pollutant control. A recent series of short-term Hg remediation tests at Alabama Power, a subsidiary of Southern Company, further demonstrates the importance of the COHPAC (Compact Hybrid Particulate Collector) technology in multi-pollutant control for coal-fired boilers.

Alabama Power already employs two COHPAC systems, supplied by Hamon Research-Cottrell, of Somerville, N.J., at its coal-fired E. C. Gaston generating plant. As a potential multi-pollutant control device, COHPAC is attractive for accomplishing a variety of controls with essentially the same capital investment. Now, with the addition of activated carbon, the system may add a major role in Hg reduction.

Southern Company has a long-standing commitment to seeking ways to produce more environmentally efficient energy. One facet of the company's environmental commitment is maintaining a toolbag of control options, including investigation of new control technologies as they are suggested and developed. The company has always been open to cooperation in control test activities, and has participated in the work of the EPA, DOE, the Electric Power Research Institute (EPRI) and others.

Investigating HG reduction

The U.S. Department of Energy's National Energy Technology Laboratory (DOE-NETL) selected Southern Company and Alabama Power to participate in the nation's first full-scale program to test advanced mercury control technologies for coal-fired power plants. Starting in March 2001, the new technology was tested at Alabama Power's E. C. Gaston generating plant near Wilsonville, Ala.

Environmental technology and chemical company ADA-ES, a subsidiary of Earth Sciences based in Littleton, Colo., was chosen by DOE-NETL to conduct the tests. DOE-NETL is funding 70 percent of the $6.8 million project. The remaining funding and support is supplied by ADA-ES, Alabama Power and several other electric groups, EPA, EPRI and Hamon Research-Cottrell.

The tests show that mercury can be removed at moderately high rates, averaging 78 percent but peaking at more than 95 percent when activated carbon is injected into the existing baghouse ash collection system.

Gaston Station was earmarked for the testing because it was already equipped with COHPAC technology. The COHPAC system, which incorporates patented technology developed by the U.S. power industry under the sponsorship of EPRI, is an excellent platform for the new, EPRI-patented TOXECON mercury reduction technology because the process involves injecting activated carbon between the electrostatic precipitator and the baghouse.

Basically, the activated carbon acts like a sponge to absorb much of the mercury that is released as part of the natural process of burning coal. The reacted carbon is then removed in the baghouse.

Trace quality control

Mercury is a difficult pollutant to capture and control because of its dilute nature. It is found in only trace quantities in coal, notes Dr. Charles Goodman, senior vice president of Research and Environmental Affairs for Southern Company.

"Compared with other emissions we already control successfully, there is a million times less mercury in power plant flue gas," Goodman says.

Mercury control has been underway in waste energy plants for several years, but these plants deal with a much higher concentration of mercury. Where the typical waste energy plant is working to reduce mercury emissions from about 75 to 6 micrograms per normal cubic meter, the typical coal-fired power plant begins with 6 micrograms per normal cubic meter mercury emissions or less.

Current research and information do not indicate a direct link between utility mercury emissions and public health effects. Nevertheless, environmental regulations are starting to be developed, and the nation's utilities are attempting to prepare for them.

One important aspect, yet to be determined, is whether controls will be applied on a per-unit basis, or as a percentage over a utility's total system capacity. Southern Company has more than 70 coal-fired units, ranging from two antique but still active 22.5 mw units to Gaston's 900 mw Unit No. 5.

The mercury tests took place on Gaston's 272 mw, COHPAC-equipped Unit No. 3 burning low sulfur Eastern bituminous coals. The initial phase of the testing consisted of six weeks of tests taking place over six months. Included in the testing were measurements of mercury levels in the raw coal, the flue gas and the flyash.

Start with COHPAC

COHPAC is a marriage of an electrostatic precipitator with a high-ratio, compact fabric filter. To date, all full-scale, successfully operating COHPAC systems have been supplied by Hamon Research-Cottrell and equipped with the company's patented low-pressure pulse-jet baghouse technology.

COHPAC technology began in the early 1990s, and was applied to coal-fired utility plants, with Southern Company heavily involved in the initial research. Alabama Power's Plant Miller was the size of the second COHPAC pilot plant, and Plant Gaston was the second full-scale installation of the technology in a coal-fired power plant.

The plexiglass model was fabricated in the Gas Dynamics Laboratory of Hamon Research-Cottrell and used in the development of the full-scale installation.

The system is designed to maintain Unit 3's outlet opacity levels below 5 percent on a 6-minute average basis, operating at a maximum gross air-to-cloth ratio of 8.5:1 utilizing on-line cleaning. Since its installation in 1996, the system is credited with enabling Unit 3 to remain in continuous compliance without the previous requirement of frequent derating.

The COHPAC system provides major reductions in total and fine particulate. With the addition of dry additives such as activated carbon, sodium or calcium compounds, the technology can also significantly reduce levels of toxic emissions. The recently completed Plant Gaston tests aimed to determine just how great a reduction can be achieved in mercury, and at what cost in price, flexibility and other efficiencies.

Preliminary conclusions

The mercury control observed in this test was limited by the amount of activated carbon that could be injected into the baghouse. Activated carbon adds to the other particulate collected in the baghouse. At some point, too much loading can lead to a situation where the baghouse cannot keep up with the needed cleaning.

In the course of these tests, the test team agreed to a limitation on carbon injection to keep cleaning frequency in the acceptable range. Even so, the amount of carbon injected caused the cleaning rate to more than double. The long-term implications may include higher costs and significantly reduced bag life.

In general, the test team is satisfied with the preliminary results. Dr. Michael Durham, president of ADA-ES, noted, “This first full-scale test confirms the technology’s potential.”

The high level of mercury control was, however, achieved in a short test of only seven days. Long-term testing will be required to fully assess the cost and performance of the technology as well as its impacts on the operation of the entire generating plant. Additional testing, which is currently scheduled at three more test sites, will also be needed to determine if the amount of reduction can be sustained over longer periods and with other types of coal.

At Southern Company, the parent company of Alabama Power, Larry Monroe heads up a four-man team concentrating on multi-pollutant control technology. Richard Miller is manager, fabric filter systems for Hamon Research Cottrell.

Full-Scale Test of Mercury Control with Sorbent Injection and an ESP at Wisconsin Electric's Pleasant Prairie Power Plant

Session AE1-C

Travis Starns, Jean Bustard, Michael Durham, Ph.D., Charles Lindsey, Cameron Martin, Richard Schlager, Brian Donnelly
ADA-ES, LLC, 8100 SouthPark Way, B-2, Littleton, CO 80120

Sharon Sjostrom, Paul Harrington
Apogee Scientific, 2875 W. Oxford Ave, Suite 1, Englewood, CO 80110

Sheila Haythornthwaite
Reliant Energy, 7 East Redwood St., Baltimore, MD 21202

Richard Johnson, Ed Morris
Wisconsin Electric-Wisconsin Gas, 333 W. Everett St., Milwaukee, WI 53203

Ramsay Chang, Ph.D.
EPRI, P.O. Box 10412, Palo Alto, CA 94393-0813

Scott Renninger
US Department of Energy, National Energy Technology Laboratory
P.O. Box 880, Morgantown, WV 26507-0880

ABSTRACT

The overall objective of this project is to determine the capabilities of injecting activated carbon ahead of particle control devices (PCD) to remove mercury and to determine the cost and impacts of this technology. These tests are part of a program funded by the Department of Energy's National Energy Technology Laboratory (NETL) to obtain the necessary information to assess this mercury control technology for coal-fired utility plants that do not have scrubbers for SO_2 control. The economics will be developed based on various levels of mercury control.

Two of the four full-scale tests scheduled in this program were completed in 2001. Results from the evaluation of carbon injection into COHPAC at Alabama Power's Plant Gaston Unit 3 burning a bituminous coal will be published in the June 2002 Special Edition of the A&WMA Journal. Final results from tests on an ESP at Wisconsin Electric's Pleasant Prairie Power Plant Unit 2 burning a PRB coal will be presented in this paper. In general, the NETL-sponsored tests include a series of parametric tests where different carbon-based and other candidate sorbents are evaluated. These sorbents are injected into the flue gas at several concentrations. The sorbent that yields the best all around performance is then used during a long-term test conducted under optimized conditions. The impact of sorbent injection on the particle control devices and ash reuse practices will be discussed, as will preliminary cost estimates for full-scale sorbent injection.

INTRODUCTION

In December 2000 EPA announced their intent to regulate mercury emissions from the nations coal-fired power plants. Draft legislation indicates that new regulations may require removal efficiencies as low as 50% or as high as 90% from existing sources. Estimates for the cost of meeting mercury regulations range from $2 to $5 billion per year for 90% removal. With mercury regulations imminent, mercury control technologies need to be proven at full scale to document performance and costs.

The most mature, retrofit technology available today is the injection of sorbents such as powdered activated carbon (PAC) into the flue gas upstream of the particle control equipment. The gas-phase mercury in the flue gas contacts the sorbent and attaches to its surface. Existing particle control equipment collects the sorbent with mercury attached along with the fly ash.

Under a DOE/NETL cooperative agreement, ADA-ES is working in partnership with PG&E National Energy Group (NEG), Wisconsin Electric, a subsidiary of Wisconsin Energy Corp., Alabama Power Company, a subsidiary of Southern Company, and EPRI on a field test program of sorbent injection upstream of existing particle control devices for mercury control. The test program, which takes place at four different sites during 2001 and 2002, is described in detail elsewhere[1]. Other organizations participating in this program as industry cost share participants include Ontario Power Generation, First Energy, TVA, Arch Coal, Kennecott Energy, Hamon Research-Cottrell, EnviroCare, and Norit Americas.

At each site sorbent injection for mercury control is implemented on full-scale particulate control equipment to obtain performance and operational data. Combustion byproduct samples are collected concurrently to determine the impact of the sorbents on waste disposal and byproduct reuse practices. The tests are conducted in three distinct phases:

1. Baseline testing;
2. Parametric testing; and
3. Long-Term testing.

Baseline measurements are conducted after the injection equipment is installed. During this phase, no sorbent is injected into the flue gas. Mercury concentrations in the flue gas are measured with a Semi-Continuous Emissions Monitor (S-CEM) and by the Draft Ontario Hydro method. During this period, operating data and coal and ash samples are also collected.

A series of parametric tests is then conducted to determine the optimum sorbent and operating conditions that would be required for several levels of mercury control. The maximum injection rate is set based on preliminary injection performance data that has been developed through slip-stream testing or modeling exercises, the practical limitations of particle control device (PCD) performance, and sorbent cost. Based on results from these tests, a two-week test under optimized conditions is conducted to assess longer term impacts to the PCD, byproduct management practices and auxiliary equipment operation. During the long-term test, mercury removal efficiencies are measured by the S-CEMs and verified by draft Ontario Hydro method measurements.

At each site, at least two sorbents are evaluated during the parametric tests. A standard powdered activated carbon (FGD), which is a lignite-derived sorbent supplied by Norit Americas Inc., is tested in all cases as the benchmark sorbent. The alternative sorbent or sorbents must be commercially available and offer an advantage over the benchmark sorbent.

Testing at two of the four sites was completed in 2001. The first test was conducted at Alabama Power's Gaston Unit 3 in the spring and results are documented in the A&WMA Special Edition Journal, published in June 2002. This site was chosen because of the particulate control configuration that exists at this plant. Specifically, the PCD consist of a hotside electrostatic precipitator (HESP) with a polishing baghouse (COmpact Hybrid PArticulate Collector - COHPAC) situated downstream. Gaston fires a variety of low-sulfur, washed bituminous coals. COHPAC-equipped units offer several advantages when combined with sorbent injection for mercury control, which include:

- Sorbents are mixed with a small fraction of the ash (nominally 1% of total ash loading to the PCD), which reduces sorbent impacts on ash reuse and waste disposal.
- Pilot plant studies and theory[2] indicate that compared to ESPs, baghouses require one-tenth the sorbent to achieve similar removal efficiencies.
- COHPAC requires much less physical space than either a larger ESP or full-size baghouse system; thus potentially representing a less costly retrofit control technology.
- Outage time for COHPAC installation can be significantly reduced in comparison to major ESP rebuilds/upgrades.

Results from Gaston showed that during a ten-day period of continuous injection at 1.5 lbs/MMacf, an average mercury removal rate of 78% was observed with short-term peak removal rates approaching 90%. PAC injection however significantly increased COHPAC cleaning frequency. New COHPAC units designed with PAC injection will need to take this into account and consider lower air-to-cloth ratios (this control equipment has been called TOXECON, which is an EPRI-patented technology where a pulse-jet baghouse is installed downstream of an existing ESP and sorbents are injected into the baghouse to control air toxics emissions, such as mercury).

The second test was conducted at Wisconsin Electric's Pleasant Prairie Power Plant (PPPP) Unit 2. This site was of key interest because it was the only plant included in the NETL program that burns western, low-sulfur sub-bituminous coal. The PCD was an ESP, which represents the PCD of choice at over 90% of nation's coal-fired boilers. Other features of this test site include:

- The ability to isolate one ESP chamber (1/4 of the unit, ~150 MW);
- The challenge of implementing mercury control at a site where baseline mercury measurements (1999) showed no significant mercury removal and a flue gas mercury dominated by the elemental species;
- A duct configuration with long, unobstructed runs that allowed adequate space for the installation of water injection lances upstream of the sorbent injection lances so that the effects of spray cooling (to achieve lower flue gas lower temperatures) on mercury control could be evaluated; and
- A keen interest in the impact of activated carbon on fly ash sold for use in concrete.

PLEASANT PRAIRIE POWER PLANT SITE DESCRIPTION

Wisconsin Electric Power Company, a subsidiary of Wisconsin Energy, owns and operates Pleasant Prairie Power Plant located near Kenosha, Wisconsin. The plant has two (2) 600 MW balanced-draft coal-fired boilers. Unit 2 was chosen to be the test unit. The units fire a variety of Powder River Basin (PRB) low sulfur, sub-bituminous coals.

The primary particulate control equipment consists of cold-side ESPs, of weighted wire design and liquid sulfur trioxide (SO_3) flue gas conditioning. The precipitators were designed and built by Research-Cottrell and the flue gas conditioning system was supplied by Wahlco. The system was originally designed to collect fly ash from the Riley Stoker turbo-fired boiler with design superheated steam conditions of 1990 psig/995^{o}F. The boiler was designed to burn low-sulfur coal at a gross nominal generating capacity of 617 MW (580 MW net). The design flue gas flow was 2,610,000 ACFM at 280^{o}F and an inlet pressure of $^+/_-$ 30" H_2O. The design collection efficiency was 99.72%. There is a common stack supporting two sister units.

Precipitator #2 was commissioned and put into service in 1985. The installation is comprised of four (4) electrostatic precipitators that are arranged piggyback style and designated 2-1, 2-2, 2-3, and 2-4. Each of the four precipitators is two (2) chambers wide and four (4) mechanical fields deep with eight (8) electrical fields in the direction of gas flow. The specific collection area (SCA) is 468 ft^2/kacfm. The unit employs sixty-four (64) T/R's, sixteen (16) on each precipitator. The T/R's are capable of double half-wave or full-wave operation. At this time, the T/R's are in full-wave operation.

Opacity is measured at the stack, but there is the capability of measuring opacity in the common ductwork for each of the two (2) piggyback ESPs.

Hopper ash is combined from all four precipitators in the dry ash-pull system. The ash is sold as a cement powder substitute in concrete and is considered a valuable byproduct. One precipitator's ash can be isolated from the balance of the unit.

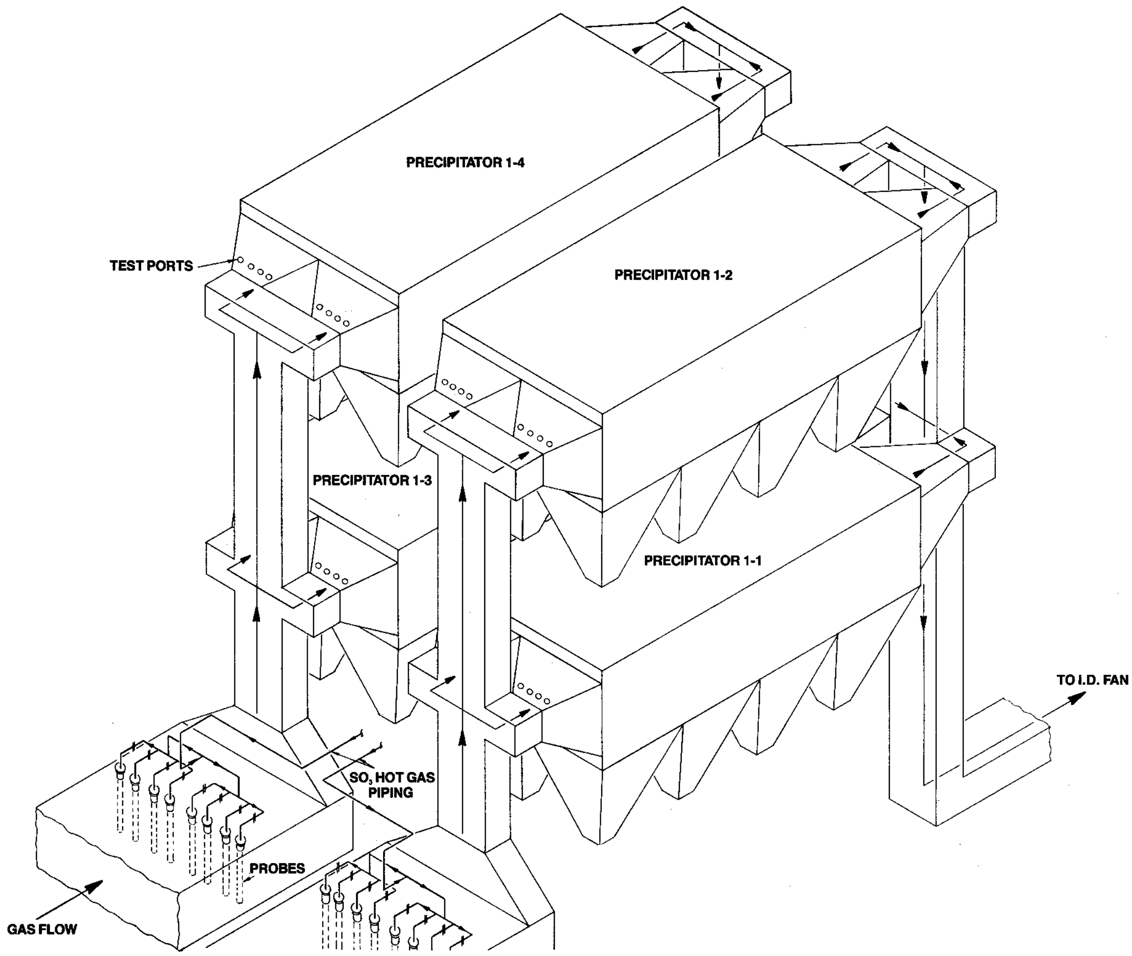
A summary of important descriptive parameters for Pleasant Prairie Unit 2 is presented in Table 1.

Table 1. Site Description Summary, Pleasant Prairie Unit 2.

Parameter Identification	Description
Process	
Boiler Manufacturer	Riley Stoker Turbo-Fired
Burner Type	Riley Stoker – Direction Flame
Low NOx Burners	No
Steam Coils	No (glycol preheater)
Over Fire Air	No
NOx Control (Post Combustion)	None
Temperature (APH Outlet)	280 ^{o}F
Coal (Typical)	
Type	Powder River Basin
Heating Value (Btu/lb)	8,400
Moisture (%)	20.1
Sulfur (%)	0.43
Ash (%)	7.5
Hg (µg/g)	0.1
Cl (%)	0.0015
Control Device	
Type	Cold-Side ESP
ESP Manufacturer	Research Cottrell
Design	Weighted Wire
Specific Collection Area (ft^2/1000 afcm)	468
Flue Gas Conditioning	Wahlco SO_3 Injection

Figure 1 shows an isometric view of the Unit 1 ESPs at PPPP. Unit 2 is identical to Unit 1. One of the four ESPs was treated, representing nominally 150 MW of the unit's total capacity. This met DOE's requirement to evaluate units no larger than 150 MW and also provided the opportunity to compare ESP performance and mercury removal on parallel ESPs, one treated with sorbent injection and one untreated. The injection tests were conducted across the 2-4 ESP.

Figure 1. Isometric View of Precipitator Arrangement at Pleasant Prairie.



The 2-4 ESP is the top box of the piggyback-configuration and therefore had a long duct run which could accommodate both sorbent injection and spray cooling, and still have adequate residence time for both.

Sorbent for mercury control was injected into the ductwork downstream of the SO_3 injection grid. The sorbent had approximately 0.75 seconds of residence time in the duct before entering the ESP.

INJECTION EQUIPMENT

The transportable sorbent injection system was provided by Norit Americas and consists of a bulk-storage silo and twin blower/feeder trains each rated at 750 lb/hr. Sorbents are delivered in bulk pneumatic trucks and loaded into the silo, which is equipped with a bin vent bag filter. From the two discharge legs of the silo, the reagent is metered by variable speed screw feeders into eductors that provide the motive force to carry the reagent to the injection point. Regenerative blowers provide the conveying air. A PLC system is used to control system operation and adjust injection rates. Figure 2 is a photograph of the sorbent silo and feed train installed at PPPP. Flexible hoses carried the reagent from the feeders to distribution manifolds located on the ESP inlet duct, feeding the injection probes. Each manifold supplied up to six injectors.

Sorbent requirements for various levels of mercury control were predicted based on empirical models developed through EPRI funding[2]. The values used were based on an in-flight model with one second residence time and uniform sorbent size of 15 microns (size of commercially available PAC). Practical limits associated with bulk handling of sorbents, storage requirements and increased loading to the ESP were also considered. Rates used to design equipment for the PPPP test are presented in Table 2. The system was sized for a maximum injection rate of 1500 lbs/h.

EnviroCare International provided the spray cooling system used to cool the flue gas temperature. The spray cooling system was comprised of a valve rack skid, air and water headers, and spray lances. Compressed air and supply water from the plant was provided to the valve rack skid where controls regulated the air and water to obtain proper flows and pressures at the spray lances. Since the volume and temperature of the gases varied across the ESP inlet duct, the spray cooling system was engineered with two control zones.

In preparation for the field test at Pleasant Prairie, the internal duct bracing within 40 feet downstream of the spray lances was removed. Feedback thermocouples were also located 40 feet downstream of the spray lances and used to regulate water flow and air pressure to the spray lances to maintain a predetermined temperature setpoint. This particular spray cooling system was designed to maintain a temperature difference of 50°F between the inlet and outlet thermocouples of the spray cooling system.

Table 2. Predicted Injection Rates for FGD Carbon on 1/4 of PPPP ESP.

Target Hg Removal Efficiency (%)	**Predicted Injection Concentration (lbs/MMacf)**	**Predicted Injection Rate[a] (lbs/h)**
20	10	360
40	20	720
50	30	1080

Note a: Injection rate based on nominal flow at full load of 600,000 acfm.

Figure 2. Carbon Injection Storage Silo and Feeder Trains Installed at PPPP.

SEMI-CONTINUOUS MERCURY ANALYZER

Near real-time vapor phase mercury measurements were made using a Semi-Continuous Emissions Monitor (S-CEM) designed and operated by Apogee Scientific. This instrument was developed with EPRI funding to facilitate EPRI research and development efforts. Two analyzers are dedicated to the program and are set up at the inlet and outlet of the PCD. The S-CEMs operate continuously over the seven-week test program at each site and provide speciated (Hg^0 and Hg^{2+}), vapor phase mercury concentrations. Details of the operation of these units are described elsewhere[1,3].

SORBENT SELECTION, FIXED BED SCREENING TESTS

Sorbents for the full-scale evaluation were selected based on several factors, including results from fixed bed screening tests for mercury adsorption capacity, price, and availability of bulk delivered sorbent at quantities up to 100,000 lbs. Norit Americas lignite-based PAC, Darco FGD, was chosen as the benchmark sorbent.

URS Corporation conducted both the laboratory and slip-stream measurements of sorbent adsorption capacity and provided technical expertise in results interpretation. URS has determined the equilibrium adsorption capacity for a variety of sorbents as a function of mercury concentration, mercury type, flue gas temperature, and flue gas composition. Results from these tests and a description of the test device and procedures have been published previously[4].

At PPPP, mercury adsorption tests were carried out on a slip-stream of flue gas extracted from two locations upstream of the ESP; before and after SO_3 injection. Eight carbon-based and three fly ash-based sorbents were tested at 250 or 300°F, with and without SO_3 conditioning. The major conclusions from the fixed-bed tests were:

- Carbons are capable of achieving high mercury capacities in PPPP flue gas;
- SO_3 appears to inhibit carbon adsorption, but not to the extent that capacity is decreased below the threshold capacity (nominally 150 µg/g for an ESP) and therefore performance should not be impacted[5];and
- Flue gas cooling significantly increased the adsorption capacity of some of the carbon-based sorbents.

Four sorbents were selected for full-scale evaluation in the parametric test series. All four sorbents were PACs because none of the ash-based sorbents met the established criteria. The alternate sorbents were chosen because they had potential advantages over the benchmark sorbent. Two sorbents had smaller size distributions, which according to theory should significantly improve mercury collection efficiency. The third sorbent was a lower capacity, lower cost PAC. A description of the four sorbents selected for the parametric test is presented in Table 3.

Table 3. Description of Norit Carbons Selected for the Parametric Tests.

Name	**Description**	**Particle Size Distribution[a]**		
		D95	**D50**	**D5**
Darco FGD	Lignite AC	52	18	<3
Darco FGL	Lignite AC	52	18	<3
Darco Insul	Fine, chemically washed specialty product	25	6-7	<2
Ground FGD	Lignite AC	50	14	<3

Note a: Percent of particles less than size in microns

TEST RESULTS

Baseline Tests

After equipment installation and checkout, a set of baseline tests was conducted. During this test boiler load was held steady at "full-load" conditions during testing hours, nominally 7:00 am to 7:00 pm. Both the S-CEMs and the modified Ontario Hydro Method were used to measure mercury across the 2-4 ESP.

Results from Ontario Hydro tests conducted by GE Mostardi Platt in September 2002 are presented in Table 4. The average flue gas temperature during this period was 290°F. The data show minimal baseline mercury removal across the ESP. The predominant species of mercury, whether at the inlet or outlet of the ESP, was elemental. Similar to measurements conducted at Gaston, there was oxidation of mercury in the direction of flow, in this case, across the ESP.

Table 4. Speciated Mercury Measured by Ontario Hydro Method, Baseline Conditions.

	Particulate (mg/dncm[a])	**Elemental (mg/dncm[a])**	**Oxidized (mg/dncm[a])**	**Total (mg/dncm[a])**
ESP Inlet	1.97	12.22	2.51	16.71
ESP Outlet	0.01	9.80	6.01	15.82
Removal Efficiency (%)	99.5	19.8	-139.3	**5.3**
% of Total at Inlet	11.8	73.1	15.0	
% of Total at Outlet	**0**	**61.9**	**38.0**	

Note a: Normal: T = 32°F

Coal samples collected during baseline tests and analyzed for mercury levels showed an average concentration of 0.099 μg/g. At PPPP a coal mercury level of 0.099 μg/g is equivalent to a mercury concentration of about 13.7 μg/dncm @ 3% O_2 in the flue gas.

Parametric Tests

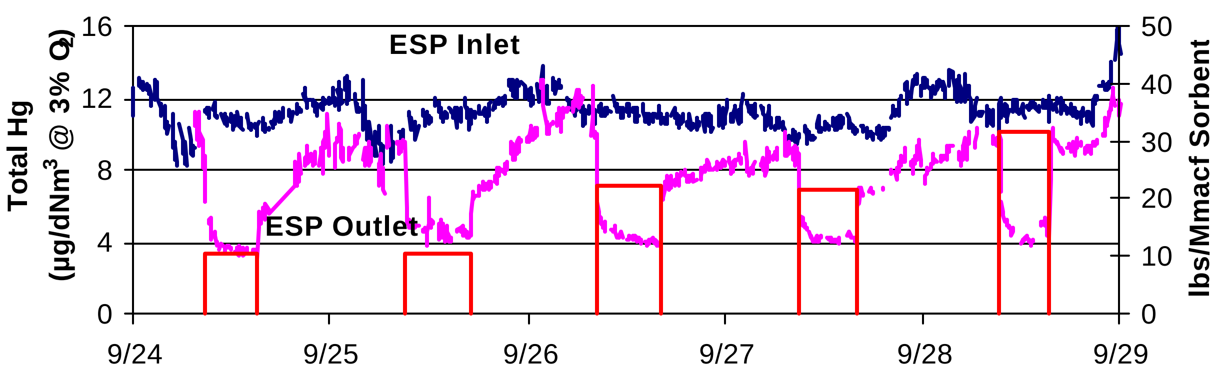
A series of parametric tests was conducted to determine the optimum operating conditions for several levels of mercury control. Primary variables were injection concentration, carbon type, SO_3 flue gas conditioning on/off and spray cooling to 250°F. In all, 16 different parametric conditions were tested. A summary of the parametric tests is presented in Table 5. Standard conditions were with the boiler at full load operation, SO_3 conditioning on, and no spray cooling. Each condition was run for a minimum of six hours, except for Test Series 13-16 where the small particle size distribution of the Insul sorbent caused feed problems.

Table 5. Summary of Parametric Test Conditions.

Test Series	Carbon Name	Target Injection Concentration (lbs/Mmacf)	Non Standard Conditions
1	Darco FGD	10	SO_3 Conditioning Off
2, 3, 5	Darco FGD	10, 20, 30	Standard
4	Darco FGD	10	Spray Cooling to 250^{o}F
6, 8, 9, 10	Ground FGD	1, 2, 5, 10	Standard
7	Ground FGD	10	SO_3 Conditioning Off
11&12	FGL	5 & 10	Standard
13 - 16	Insul	0.5, 1, 2, 3	Standard

Mercury removal was monitored as a function of the sorbent injection concentration. In addition, the impact of sorbent injection on the performance of the ESP was monitored. An example of the data from the S-CEMs during the first week of parametric testing is presented in Figure 3. These five tests were conducted with Darco FGD. SO_3 conditioning was off on September 24 and spray cooling to 260 and 250^{o}F was evaluated on September 27. Reduction and recovery of outlet mercury concentration can be seen to correlate with periods of sorbent injection. Inlet mercury levels varied between nominally 9 and 13 µg/dncm. During sorbent injection, outlet mercury concentrations decreased to a minimum of about 4 µg/dncm. In most cases the outlet mercury levels recovered to baseline levels within 10 – 12 hours after sorbent injection was stopped.

Figure 3. S-CEM Mercury Measurements During the First Week of Parametric Tests with Norit Darco FGD PAC.



The early tests showed a couple of surprising trends. First, the mercury removal efficiencies were significantly higher than expected at the lower injection concentrations. The model predicted about 20% in-flight removal at a sorbent injection rate of 10 lb/Mmacf. An actual mercury removal rate of between 60 and 65% was measured during the two 10 lb/Mmacf test conditions. The in-flight model did not take into account mercury removal due to sorbent being deposited on internal structures, such as turning vanes, or on the ESP plates. It appears that the contribution from the carbon on the plates and other structures in the ESP to overall mercury removal was significant. The second unexpected trend was that mercury removal efficiencies did not increase to greater than nominally 60% at higher injection concentrations of 20 and 30 lbs/MMacf.

Spray Cooling Test

The first week of testing also included an evaluation of spray cooling. Flue gas temperature entering the 2-4 ESP deviated from north to south by nominally 40°F, based on air heater rotation. The north side average temperature was about 300°F at the start of the spray cooling test. Water was injected so that the average temperature 40ft downstream of the water injection lances, as measured by the thermocouple array, was 260°F, or a 40°F decrease on the north side and a 20 °F decrease on the south side. When no enhancement of mercury removal was seen after several hours, the injection rate was increased to obtain a flue gas temperature of 250°F. To achieve this level of cooling, 18 gpm of water was being injected. Because of the pozzalonic nature of the PRB ash, the internal ductwork and the sorbent injection lances (40 ft downstream of the spray lances) were monitored closely with an in-duct camera and by manual inspection of the sorbent lances. No sign of deposition was seen at 260°F. However, after less than 50 minutes of cooling to 250°F, deposition was building on the sorbent lances on the north side. No improvement in mercury removal was measured at these lower temperatures and because deposition was noted, the spray cooling test was terminated.

These results were not surprising because similar trends have been seen during slipstream testing by EPRI on PRB coal-derived flue gases. Based on work at other coal-fired units, lower temperatures increase the adsorption capacity of most sorbents. But as stated earlier, the PAC adsorption capacities are already much higher than the threshold capacity needed for effective mercury removal. Increasing the capacity via flue gas cooling did not result in increased removal efficiency. However, operating in the ideal temperature range is still an important concept as it relates to the control of mercury. There are conditions where cooler temperatures may enhance or allow sorbents to be more effective for mercury control. Additional testing needs to be conducted at plants whose operating temperatures are above 360°F.

Effect of SO_3 Conditioning

Sorbent screening tests showed that SO_3 conditioning decreased the adsorption capacity of the carbon sorbents. The difference in mercury removal during the first test with and without SO_3 conditioning was 60 versus 65%, respectively. This is almost a 10% difference, which is the level of accuracy we believe is repeatable in these tests. To confirm whether SO_3 conditioning really had an impact on sorbent effectiveness, the same test conditions, 10 lbs/MMacf with and without SO_3 conditioning, were repeated with the ground FGD during the second week. The results were 60% removal with SO_3 and 63% removal without SO_3. Data from the two sets of tests indicate that there was no significant effect on mercury removal with PAC injection when SO_3 conditioning was in-service.

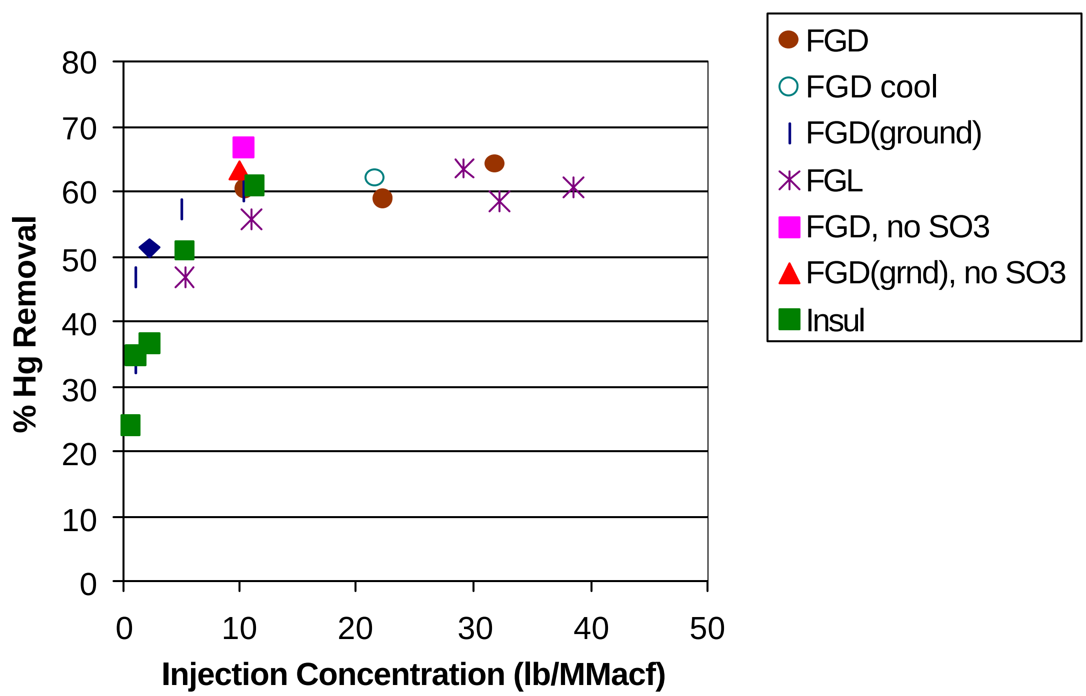
Parametric Test Summary

A summary of results from all the parametric tests is presented in Figure 4. This figure plots mercury removal efficiency as a function of sorbent injection concentration. The different symbols represent different test conditions including carbon type, SO_3 off and spray cooling. This graph shows that there was a rapid increase in mercury removal with PAC injection up to an injection concentration of about 5 lbs/MMacf. Increasing the sorbent injection rate from 5 to 10 lbs/Mmacf showed an incremental 10% increase in mercury removal. No significant additional removal was observed when the rate of sorbent injection was raised above 10 lbs/MMacf.

As stated above, this apparent ceiling of 70% removal was surprising. Poor sorbent distribution in the gas stream could contribute to this problem. To prove that distribution was not a problem, several tests were conducted with the injection lances in different configurations that would alter distribution patterns. No measurable change in mercury removal was noted.

There was no significant difference in performance among the four carbons, even with the finer grain carbons. The finest carbon, Insul with a D50 of 7µm, was difficult to feed because of bridging in the discharge legs of the silo. Design changes would have to be incorporated into this system to feed finer carbons.

Figure 4. Mercury Removal Trends Across ESP as a Function of PAC Injection Concentrations. Measurements Made During Parametric Tests, Sept-Oct 2001.



One of the significant observations made during the testing was that carbon injection had no impact on the performance of the ESP. Some improvement in power levels were seen during the spray cooling tests.

Long-Term Tests

Long-term testing under optimum conditions, as determined from the parametric tests, was performed to gather data on:

- Mercury removal efficiency over time;
- The effects of sorbent injection on ESP performance and balance of plant equipment; and
- Operation of the injection equipment to determine the viability and economics of the process.

The original test plan called for injecting sorbents at one condition, 24 hours/day, for up to two weeks to obtain the highest mercury removal rates possible within equipment limitations. However, results from the parametric tests showed significant mercury removal at low injection rates. This raised interest in the long-term performance under these conditions. The long-term test was divided into three injection periods, each lasting five days, to determine:

1. The ability to achieve significant mercury removal (40 –50%) at a low sorbent injection concentration. The interest here was to obtain representative ash samples at this low rate to determine the impact on existing, valuable reuse of the PPPP fly ash. At 1 lb/MMacf the estimated increase in ash LOI was 0.5%.
2. Mercury removal at a high sorbent injection concentration and the impact on ESP performance. An injection concentration of 10 lbs/MMacf was chosen because no additional mercury removal was measured at higher injection rates; and
3. If the relationship between mercury removal and sorbent injection concentration obtained during the parametric tests was the same with long-term operation. An intermediate sorbent injection concentration of 3 lbs/MMacf was chosen.

Darco FGD activated carbon was chosen as the sorbent for these tests. Similar to the baseline test series, mercury was measured by both the S-CEMs and manual methods (Ontario Hydro). The Ontario Hydro measurements were performed only once during the long-term tests at the highest injection concentration, 10 lbs/MMacf. ESP performance, coal and fly ash samples, and plant CEM data were collected. Full load boiler conditions were held between the hours of 7:00 am to 8:00 p.m., with load under dispatch control at other times, except for the three days when the Ontario Hydro tests were conducted and full load was maintained 24 hours/day. Table 6 presents the schedule for the long-term tests and the goals associated with each condition.

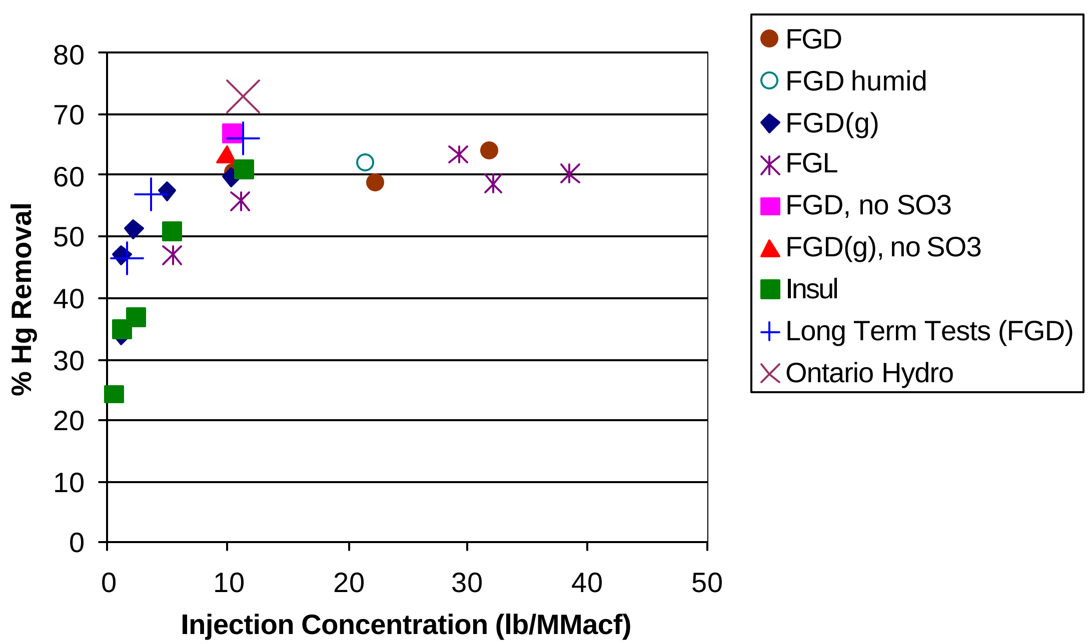
Table 6. Long-Term Test Conditions and Goals.

Dates	Target Injection Concentration	Test Goals
10/31/01 – 11/4/01	1 lb/MMacf	1. Minimize impact on ash 2. Measure mercury removal at low injection rate
11/5/01 – 11/9/01	3 lb/MMacf	1. Measure mercury removal at logarithmic "middle" point
11/10/01 – 11/14/01	10 lb/MMacf	1. Measure mercury removal at high injection rate 2. Determine impact on ESP 3. Conduct Ontario Hydro mercury measurements

Long-Term Test Mercury Removal Results

Figure 5 presents mercury removal with respect to PAC injection concentration for both the parametric and long-term tests. Mercury removal rates as measured with the S-CEMs for each of three long-term test conditions can be seen as the large crosses at 1.6, 3.7, and 11.3 lbs/MMacf. These data points represent the average over the entire 5-day period. The average mercury removal was 46% at 1.6, 57% at 3.7, and 66% at 11.3 lbs/MMacf. These results fall within the trends developed during the parametric tests, showing that no significant additional increase in mercury removal was achieved with longer run times.

Figure 5. Mercury Removal Trends for Parametric and Long-Term Tests at PPPP.



Three sets of Ontario Hydro measurements were made at the inlet and outlet of the 2-4 ESP and the average removal efficiency is shown in Figure 5 as the large X at 11 lbs/MMacf. Results from the Ontario Hydro measurements are presented in Table 7. The average inlet mercury concentration was 17.4 µg/dncm, with over 80% being measured as elemental mercury. Coal samples taken during this period had an average mercury level of 0.133 µg/g, or an equivalent flue gas concentration of 21.7 µg/g. The outlet mercury concentrations show the effect of carbon injection with lower mercury emissions for all species and 70.4% and 74.5% reduction of the elemental and oxidized species respectively. The overall average reduction in total mercury was 72.9%. At the outlet the predominant species of mercury is the elemental form; however, it is still 70% less than what was present upstream of PAC injection.

Table 7. Speciated Mercury Measured by Ontario Hydro Method, Long-Term Tests at PAC Injection Concentration = 11 lbs/MMacf.

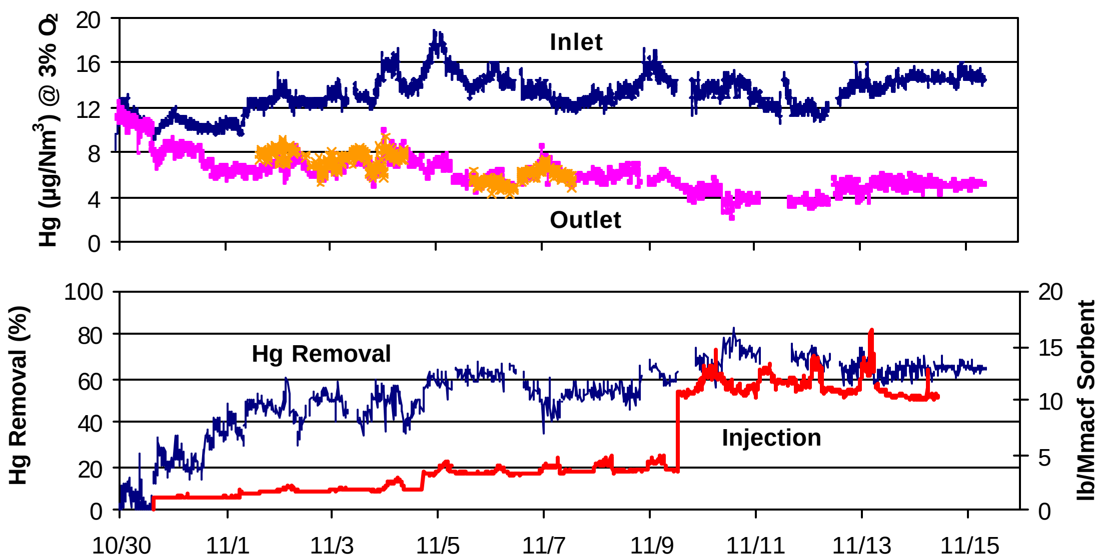
	Particulate (mg/dncm[a])	**Elemental (mg/dncm[a])**	**Oxidized (mg/dncm[a])**	**Total (mg/dncm[a])**
ESP Inlet	1.0	14.7	1.7	17.4
ESP Outlet	0	4.3	0.4	4.7
Removal Efficiency (%)	**100**	**70.7**	**74.5**	**72.9**
% of Total at Inlet	5.7	84.5	9.8	
% of Total at Outlet	0	91.5	8.5	

Note a. Normal: T = 32^{o}F

The S-CEM and Ontario Hydro removal efficiency results show good correlation, within 10%. The was the case even though the S-CEM measures only vapor phase mercury and the Ontario Hydro measurements showed nearly 6% particulate mercury at the inlet.

Figure 6 presents inlet and outlet mercury concentrations as measured by the S-CEMs, mercury removal across the ESP, and PAC injection concentration during the long-term test. Inlet mercury concentration varied between 10 and 17 µg/dncm. During the first two days of the long-term test at the low injection rate, outlet mercury levels slowly decreased to about 6.5 µg/dncm. Outlet mercury can be seen to follow inlet mercury levels, especially when mercury concentration increased on November 12, 2001.

Figure 6. Inlet and Outlet Mercury Concentrations, Removal Efficiencies and PAC Injection During Long-Term Test at PPPP, November 2001.



ESP Performance

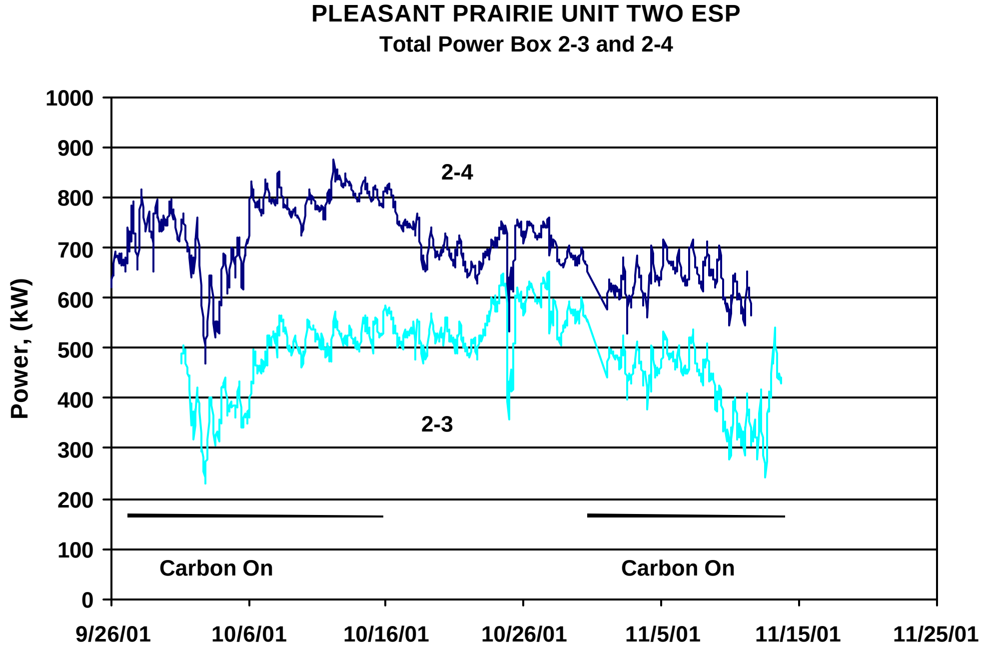
Figure 7 presents total power for the test ESP, 2-4, and the control ESP, 2-3, for the period starting September 26 through November 15. The data show that there was no negative impact on ESP performance when carbon was injected either during the parametric or long-term tests. Slight increases in power levels on the test side are within in normal variation between the two units.

Ash Characterization

Wisconsin Electric has invested significant efforts to reach a 97% utilization of ash produced by its coal-fired boilers. The fly ash from PPPP is sold for use in concrete and is a cream colored, highly desirable product. The effects of carbon injection on the salability of this ash were of prime concern. Reaction Engineering managed all of the fly ash and coal sample analyses during this program. Ash analyses performed on the samples included:

- LOI;
- Mercury;
- Leaching (TCLP and SGLP);
- ASTM C618; and
- Foam index.

Figure 7. Comparison of Unit 2-4 (with PAC Injection) and 2-3 ESP Total Power Levels During Parametric and Long-Term Tests, September – November 2001.



Preliminary analysis of the ash showed:

- LOI increased to 3 – 4% at an injection concentration of 10 lbs/MMacf from a baseline of 0.6%.
- LOI increased to 1% at an injection concentration of 1 lb/MMacf.
- TCLP and SGLP showed no detectable leachable mercury. Long term SGLP (Synthetic Ground Water Leaching Protocol) was run for 60 and 90 days.
- Mercury in the ash increased from baseline levels of <0.2 µg/g up to 5 µg/g during the long-term tests.
- Fly ash from the long term tests conformed with ASTM C618 by having LOI levels less than 6% and being within range in all other parameters.
- Ash samples with carbon at any concentration failed foam index tests. These are field tests used to determine the amount of Air Entrainment Additives needed to meet freeze thaw requirements.
- Fly ash samples with even low concentrations of carbon were discolored.

The results from the foam index tests were the most important because failure of these tests prohibited PPPP from selling this ash. In fact, the ash failed foam index tests for five weeks following the end of the carbon injection tests.

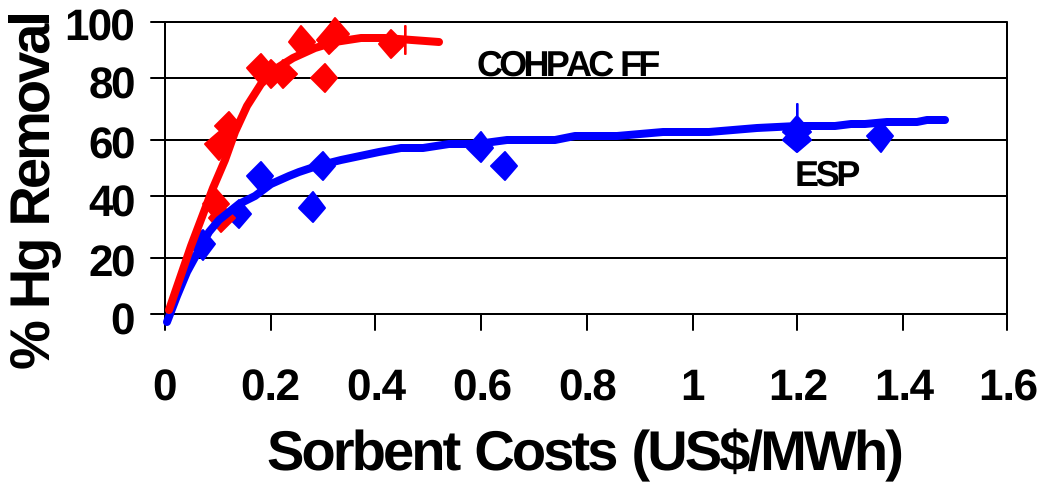
PAC ANNUAL COSTS

The requirements and costs for full-scale, permanent, commercial implementation of the necessary equipment for mercury control using PAC injection technology are being finalized for PPPP Unit 2. Preliminary capital and sorbent costs for 60% mercury removal using sorbent injection into the ESP have been developed.

The estimated uninstalled cost for a sorbent injection system and storage silo for the 612 MW Unit 2 is $720,000 ± 30%. Sorbent costs were estimated based on a long-term PAC injection concentration of 10 lbs/MMacf. For PPPP Unit 2, this would require an injection rate of nominally 1,400 lbs/h. Assuming a unit capacity factor of 80% and a delivered cost for PAC of $0.50/lb, the annual sorbent cost for injecting PAC into the existing ESP would be about $5,000,000. PAC costs for 50% control at an injection concentration of 1 lb/Mmacf would be about $600,000. Additional cost information is being developed for balance of plant impacts.

Results from the field tests conducted, to date, indicate different levels of mercury removal can be achieved depending on the particle control device. Data collected from the field test at Gaston indicate mercury removal levels of up to 90% were obtained with COHPAC (a baghouse). Even with spray cooling, the ESP collecting PRB ash was limited to levels of 50-70% at PPPP. Figure 8 presents a summary of the mercury removal trends measured at both Gaston and PPPP and the projected annual sorbent costs of PAC in $/MWh.

Figure 8. Comparison of Projected, Annual Sorbent Costs for an ESP and COHPAC Fabric Filter Based on Results from NETL Full-Scale Tests, 2001.



CONCLUSIONS

A full-scale evaluation of mercury control using activated carbon injection upstream of an ESP was conducted at Wisconsin Electric's Pleasant Prairie Power Plant Unit 2. Results and trends from these relatively short-term tests were encouraging, but identified issues with ash reuse in concrete. The overall test conclusions are.

- Effective mercury removal between 40 – 50% was obtained at 1 lb/MMacf.
- Effective mercury removal between 50 – 60% was obtained at 3 lb/MMacf.
- Effective mercury removal between 60 – 70% was obtained at 10 lb/MMacf.
- PAC injection effectively reduced both elemental and oxidized mercury concentrations.
- Fly ash could not be used for concrete with any trace of PAC present.
- No detrimental impact on ESP performance.
- On a PRB ash, if the gas temperature is below 300 ^{o}F, it appears that additional cooling does not improve mercury capture.
- Increasing injection concentration above 10 lbs/MMacf did not increase mercury removal.

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